MATURITY AND FECUNDITY OF BIGEYE TUNA IN THE PACIFIC

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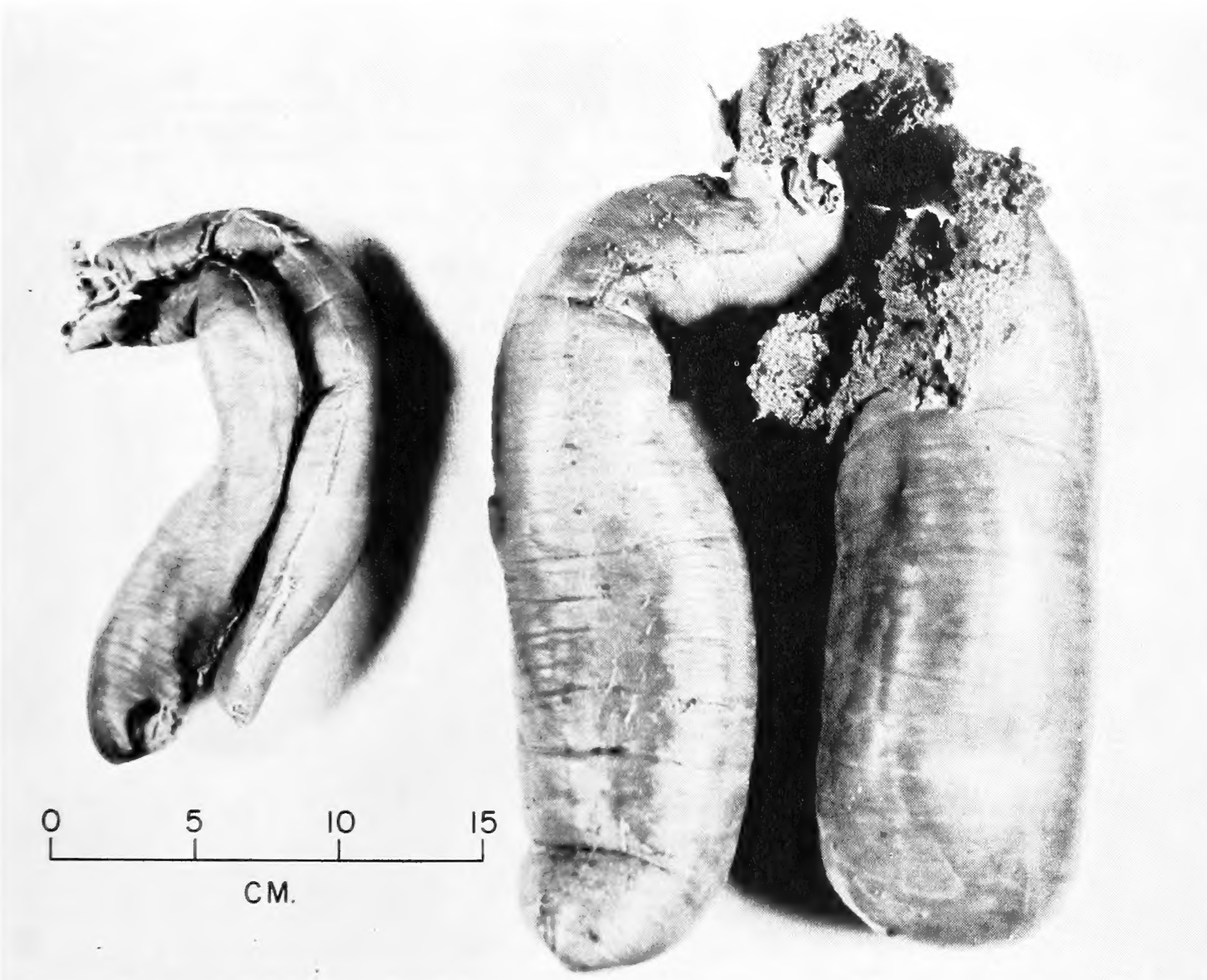

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By

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Fishery Research Biologist
Pacific Oceanic Fishery Investigations
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ABSTRACT

This study on bigeye-tuna spawning is based on ovaries from 700 fish collected in the central equatorial, western equatorial, and Hawaiian areas of the Pacific.

A critique on methodology is included. Egg distributions in different parts of an ovary and in the right and left members of a pair of ovaries were examined to establish a procedure which would give reliable samples for egg diameter frequencies. Two methods of measuring eggs were compared for efficiency. The error resulting from the use of ovary weight relative to body weight as a measure of the degree of ripeness was estimated.

Frequency distributions of egg diameters from maturing ovaries are multimodal with a maximum of four modes. The size at which the bigeye first spawns was found to be 14 to 20 kg. Spawning, which seems to be a year-round occurrence, takes place in the central and western equatorial areas but not in the Hawaiian area. There is evidence of more than one spawning per year with the number of eggs per spawning ranging from 2.9 to 6.3 million.

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MATURITY AND FECUNDITY OF BIGEYE TUNA IN THE PACIFIC

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The bigeye tuna, Parathunnus sibi (Temminck and Schlegel), is one of several commercially important tunas of the central and western Pacific. In the 7-year period of 1946 through 1952 the annual catch of the bigeye in the longline fishery of Hawaii increased from 63 tons to over 1,000 tons (Otsu 1954). The Pacific Oceanic Fishery Investigations (POFI), investigating the tuna resources of the Pacific, is interested in the commercial potentialities of this species, the first in importance in the commercial longline catches of the Hawaiian area (Otsu 1954) and second to the yellowfin in the western equatorial Pacific (Van Campen 1952).

In order to understand this increase in the catch and to evaluate the commercial potentialities of the bigeye, there is need for more information on its biology and the factors contributing to the temporal and geographic variations in its distribution. The aspects of spawning covered by this study should supply part of the required information. Knowledge of fecundity and age at maturity may help in estimates of abundance. Information on the time and place of spawning not only may explain some of the distributional variations but will facilitate the collection of the embryos and larvae which are necessary for early life history studies.

The basic method of study was the microscopic examination and measurement of eggs taken from the ovaries, as described by Clark (1934).

Papers on bigeye spawning by Shimada (1951) and Kikawa (1953) deal primarily with the time of spawning in the western equatorial Pacific. They found fish in advanced stages of maturity throughout the periods covered by their studies, June to September 1950 and June to August 1951. Keats Bank in the Marshall Islands was suspected by Kikawa to be an area of spawning concentration. Two reports on the occurrence of bigeye young may have some bearing on the time and place of spawning. In one report, Kishinouye (1919) mentioned two postlarval forms which he believed to be bigeye in the stomach of a skipjack, Katsuwonus pelamis (Linnaeus), caught at Nakasone (28°10'N., 129°15'E.) during May. In the other, Marukawa (1941) reported finding juveniles in the stomachs of yellowfin tuna, Neothunnus macropterus (Temminck and Schlegel), caught in the Tokobei area (Tobi Island, 3°N., 131°31'E.). He did not give the date of capture.

The collection of the ovaries on which this study is based was initiated by Mr. Fred June. Material from the western equatorial Pacific was collected by Messrs. K. Ego, T. Otsu, and W. Van Campen, who with other members of the POFI scientific staff also participated in collecting in the Hawaiian and central equatorial Pacific areas. Dr. A. L. Tester of the University of Hawaii and Mr. O. E. Sette, Director of POFI, made valuable suggestions concerning analytical procedures. The assistance and cooperation of these supervisors and colleagues are gratefully acknowledged.

MATERIALS AND SAMPLING METHODS

For this study ovaries taken from fish captured on longline gear were preserved in approximately 10-percent formalin. Material from the Hawaiian area was obtained at the auction room of the Kyodo Fishing Company, Ltd., where most of the catch of the Honolulu longline fleet was sold. Here the ovaries were taken from fish that had been kept on ice for as long as 3 weeks after capture. Over a period of 2 years, beginning in November 1949, ovaries of 503 bigeye were collected. POFI observers with Japanese tuna mothership expeditions that operated among the Marshall and Caroline islands in the area bounded by 1° and 10° N. latitude, 145° and 179° E. longitude during the period of April to October 1951 collected ovaries from bigeye captured there. Collections from the central equatorial Pacific were made on POFI exploratory fishing expeditions, which covered an area bordered by the latitudes of 17° N. and 10° S. and the longitudes of 170° W. and 119° W. These cruises covered a period of 2 years from August 1951 to August 1953 and produced collections of ovaries for all months except April and December.

Data recorded at the time of collection included the weight or fork length of the fish, or both, and the date and location of capture. The ovaries were weighed at the laboratory after excess tissues such as the mesovarium and the attached blood vessels had been removed. The data are presented in the appendix.

Because the ovaries were obtained from longline catches as opportunity arose, the collections were deficient in several respects. The coverage of time and space was sparse, and bigeye below 30 kg. (66 lbs.) were not well represented in the longline catches.

DESCRIPTION OF OVARIES

The ovaries are paired elongate organs, circular in cross-section, lying along the dorsal wall of the body cavity. They are separate from each other except posteriorly, where the oviducts join just before entering the cloaca. In immature fish (13 kg., or 29 lbs., was the weight of the smallest examined) the ovaries are small (about 1 cm. in diameter) and firm. As the fish approach spawning condition, their ovaries become enlarged both in length and in girth. A large ripe fish may have ovaries as much as 10 cm. in diameter. The ovaries are rather flaccid when spent.

Longitudinal projections of the ovary wall incompletely partition the lumen and serve as supports for the follicular tissue. Cross-sections of immature ovaries show a plumate arrangement of the follicular tissue with the partitions as "rachises". This arrangement is obscured by large ova in maturing and mature ovaries.

DESCRIPTION OF EGGS

As in other fishes, the ovary of the bigeye contains a large reserve of small, transparent "primitive" or undeveloped eggs which periodically give rise to smaller numbers of developing eggs. The number of undeveloped eggs in a pair of ovaries, as estimated from a frequency distribution of diameters of all eggs in the ovary (fig. 1), is approximately 1 billion. The primitive eggs average 0.07 mm.[1/] and may be as large as 0.18 mm. in diameter. As these eggs develop, the deposition of yolk granules enlarges them and makes them opaque. They are fully opaque at a diameter of 0.20 mm. at which stage the weight of the ovary is about 0.004 of the weight of the fish (see page 10). Continuing deposition of yolk granules causes further enlargement of the egg, and when a diameter of 0.75 mm. is reached, oil globules begin to appear.

The beginning of translucence in larger eggs signifies the approach of ripeness. The mature eggs are translucent and spherical. Diameter frequencies of this group show modes at 0.88 mm. to 1.1 mm. Each ovum contains, in a sac, an oil globule, which appears as a yellow spot measuring 0.240 to 0.274 mm. in diameter. The oil is sometimes divided into smaller, brighter yellow spots due to the rupture of the sac. When this happens, the empty sac is usually seen with ease under magnification.

[1/] Based on formalin-preserved material.

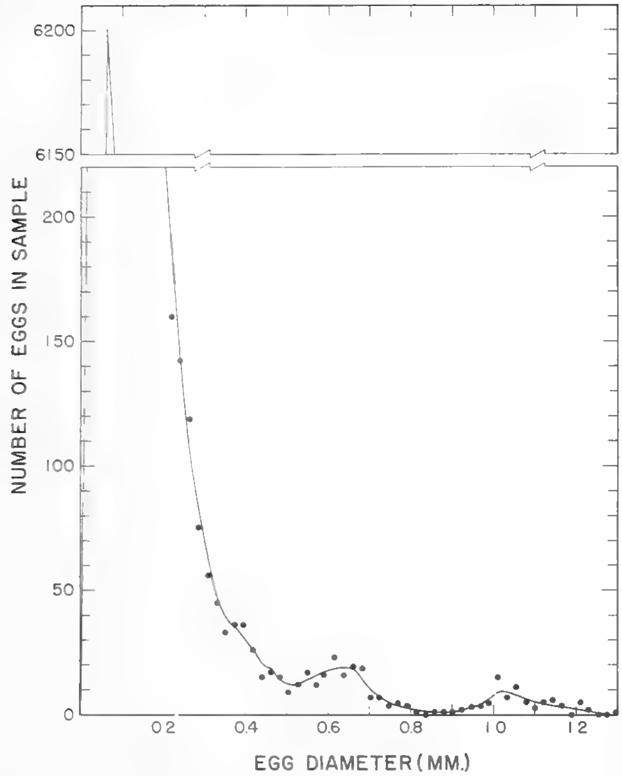

Figure 1.--Frequency distribution of egg diameters from the ripest ovary from the central equatorial Pacific (no. 57).

When the fish spawns, some mature eggs remain in the ovary and are reabsorbed. These residual eggs can be recognized by their shriveled appearance and dark coloration. In late stages of reabsorption they are often arranged in dark clumps like a string of misshapen beads imbedded in the follicular tissue.

In this paper the ovaries will be designated immature, early maturing, late maturing, and mature according to whether they are found with primitive eggs only, with opaque eggs before the appearance of oil globules, with opaque eggs with oil globules, or with large eggs which are translucent.

ESTABLISHMENT OF SAMPLING PROCEDURES

Determining the most efficient method of measuring diameters

Although basically spherical, the eggs are distorted by pressure from other eggs in the ovary. This posed a problem concerning the most efficient method of measuring an egg. One alternative was to measure the maximum and minimum diameters and average them; another was to measure the diameter which occurred, by chance, parallel to guide lines ruled in the Sedgewick-Rafter counting chamber used as a receptacle during the measuring. Both of these techniques provide estimates of the average diameter, but a greater variance would be expected with the latter that would make it less efficient. To compare the variances, 50 mature eggs were measured from an ovary (no. 24) by both procedures. The results of the measurements are recorded in units of 7.5 microns in table 1.

If the relative efficiency of the two methods is judged by their variances, 37.59 and 88.35 respectively for the averages of the maximum and minimum diameters and for the random diameters, obtaining the average diameter is 2.4 times as efficient as measuring the random diameter. In terms of work involved, however, the statistically more efficient method would require two measurements, each of which would be more time consuming than the one measurement of the random diameter. Still more work would be required to calculate the average. Measuring the random diameters was, therefore, the method selected. This diameter may be defined as the distance between two parallel lines tangent to the egg and normal to the rulings on the counting chamber.

Distribution of eggs within an ovary

The distribution of the most mature group of eggs within an ovary was studied as a further preliminary step in establishing a procedure for sampling each ovary. Cross-sections were taken from the anterior, middle, and posterior parts of the right member of the largest and seemingly most mature pair of ovaries in the collection at that time (no. 63). The sections were labelled _1_, _2_, and _3_ respectively. From each section six samples, two near the periphery (labelled A_1 and A_2), two near the center (labelled C_1 and C_2), and two from between these positions (labelled B_1 and B_2) were taken with a cork borer 8 mm. in diameter. It was not possible, however, to obtain more than one sample from the center position of the posterior

section. These samples were weighed to the nearest 0.001 gm. The eggs of the most mature group were counted and measured to the nearest 0.02 mm. The resulting measurements and weights are recorded in table 2. The measurements, coded by subtracting 60 and multiplying by 100, were treated with an analysis of variance test (table 3). Because of the lack of one sample, the analysis of variance for data based on a single classification with unequal subsample numbers (Snedecor 1946:240-241) was used. This test showed a significant difference ($P < 0.05$) in the diameter means between positions (A, B, and C) but none between sections. The means for positions A, B, and C were 0.9606 mm., 0.9640 mm., and 0.9447 mm. respectively.

Table 1.--Maximum, minimum, and random egg diameter measurements for a single ovary (no. 24) (in micrometer units of 7.5μ)

Chance diameter	Maximum diameter	Minimum diameter	$\bar{x}$	Chance diameter	Maximum diameter	Minimum diameter	$\bar{x}$
130	161	130	145.5	144	146	116	131.0
139	139	127	133.0	132	133	110	121.5
122	142	120	131.0	140	166	128	147.0
141	152	137	144.5	138	144	135	139.5
139	143	133	138.0	129	135	124	129.5
134	138	123	130.5	135	135	124	129.5
131	132	131	131.5	150	154	119	136.5
126	142	121	131.5	132	144	128	136.0
139	139	125	132.0	134	152	129	140.5
127	130	121	125.5	143	152	124	138.0
130	140	120	130.0	136	145	127	136.0
124	155	116	135.5	110	149	109	129.0
144	144	115	129.5	132	141	129	135.0
141	145	124	134.5	126	126	123	124.5
156	156	135	145.5	142	144	134	139.0
153	153	129	141.0	107	142	106	124.0
142	143	135	139.0	143	162	127	144.5
127	155	121	138.0	138	147	132	139.5
129	140	129	134.5	128	135	124	129.5
136	146	124	135.0	121	155	121	138.0
128	149	110	129.5	144	144	127	135.5
133	135	125	130.0	127	159	109	134.0
131	138	127	132.5	131	152	131	141.5
126	129	111	120.0	134	137	129	133.0
143	153	118	135.5	125	154	125	139.5

The number of mature eggs to be expected from 0.5 grams of each sample was calculated and an analysis of variance was applied to these numbers to examine differences in the number of mature eggs per unit weight between sections and between positions. The test (table 4) showed that the mature eggs were evenly distributed throughout the ovary.

In view of these results it was decided that sampling should be done in such a manner that the eggs would be randomly picked from a cross-section of the ovary. The sampling procedure described in a later section was therefore adopted.

After the study was nearly complete, however, it was noticed that the eggs near the periphery of the ovary were always easier to tease apart than those towards the center because of a less compact arrangement of eggs in this region. This caused the homogeneity of the diameter variances between positions to be questioned, as the measuring technique used would cause the greater irregularity of egg shapes resulting from greater compactness to increase the variance in the center. In a test of homogeneity (Snedecor 1946, p. 249) the variance of 0.0035 for position A was found to differ significantly from those of positions B and C, which were

Table 2.--Weights and egg diameter frequencies of samples from the various parts of an ovary (no. 63)

Diameter (mm.)	Sample number and sample weight (gm.)																
	$1A_1$ 0.0804	$1A_2$ 0.1038	$1B_1$ 0.1037	$1B_2$ 0.1034	$1C_1$ 0.1323	$1C_2$ 0.0896	$2A_1$ 0.0862	$2A_2$ 0.1203	$2B_1$ 0.1113	$2B_2$ 0.0981	$2C_1$ 0.0923	$2C_2$ 0.1189	$3A_1$ 0.1313	$3A_2$ 0.1363	$3B_1$ 0.1222	$3B_2$ 0.1330	$3C_1$ 0.0807
0.68	-	-	-	1	-	-	-	-	-	-	2	-	-	-	-	-	-
0.70	-	-	-	0	-	-	-	-	1	-	0	2	-	-	-	-	-
0.72	-	-	1	1	2	-	-	-	1	1	1	0	-	-	-	-	-
0.74	-	-	0	0	2	-	-	-	3	0	4	1	-	1	1	-	2
0.76	-	-	4	1	4	-	-	-	2	0	2	3	-	0	1	1	0
0.78	-	-	2	0	3	2	-	-	1	3	0	2	-	1	0	1	1
0.80	-	1	4	0	0	1	1	-	4	2	4	4	1	0	5	0	1
0.82	1	0	6	3	8	2	2	6	7	3	9	7	1	1	3	3	4
0.84	0	0	3	2	4	3	2	5	6	5	9	14	4	3	9	3	2
0.86	3	1	8	4	12	9	4	10	8	5	8	14	10	3	10	2	1
0.88	5	6	3	4	11	7	10	9	8	7	11	12	5	8	20	6	5
0.90	6	3	12	10	13	6	5	17	7	12	9	10	19	16	17	9	10
0.92	10	14	14	18	16	11	9	21	9	14	9	13	21	18	13	16	12
0.94	9	15	13	12	10	10	18	25	10	15	10	19	25	25	16	19	9
0.96	13	21	6	19	14	12	20	20	6	11	7	13	28	33	15	14	7
0.98	13	15	8	18	24	11	17	20	14	14	14	11	29	20	7	23	9
1.00	14	18	13	7	18	8	18	16	12	16	14	8	16	17	9	21	11
1.02	13	12	16	8	7	8	13	12	9	7	5	11	9	15	15	12	5
1.04	8	8	3	5	12	6	4	2	4	6	5	7	8	18	8	14	6
1.06	7	2	7	6	12	3	4	2	10	9	5	3	5	6	8	10	7
1.08	5	1	5	5	6	4	2	3	5	3	2	5	3	1	3	6	4
1.10	4	0	3	1	4	1	-	2	4	4	1	2	1	3	3	3	1
1.12	2	1	1	0	6	1	-	-	2	2	1	1	1	-	2	0	0
1.14	0	-	2	3	7	-	-	-	3	1	-	1	-	-	1	2	3
1.16	1	-	2	2	2	-	-	-	2	0	-	1	-	-	-	1	1
1.18	-	-	-	-	1	-	-	-	0	1	-	0	-	-	-	-	1
1.20	-	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-
Sum	114	118	136	130	198	105	129	170	140	141	132	165	186	189	166	166	102

0.0073 and 0.0083 respectively. Comparisons of the variances of the different sections showed that these also were not alike. The variance of 0.0048 for section 3 was significantly smaller than the variances of 0.0066 and 0.0070 for sections 1 and 2 respectively.

Table 3.--Analysis of variance of diameters of mature eggs from different parts of the ovary

Source	Degrees of freedom	Sum of squares	Mean square
Between sections	2	2727.861	1363.931
Positions of the same section	6	2910.770	485.128*
Samples of the same position	8	666.086	83.261
Individuals of the same sample	2470	150010.449	60.733
Total	2486	156315.166	

Table 4.--Analysis of variance of numbers of mature eggs from different parts of the ovary

Source	Degrees of freedom	Sum of squares	Mean square
Between sections	2	8527.084	4263.542
Positions of the same section	6	7842.203	1307.034
Samples of the same position	8	30176.967	3772.121
Total	16	46546.254	

The diameter means of the positions and the sections were therefore recompared by a test that adjusted for the heterogeneity of variances (Cochran and Cox 1950). Not only was a difference found in the means between positions but between sections as well. The mean of position C, when compared with those of A and B, produced "t" values of 4.004 and 4.641, which are beyond the 0.001 probability level. Significant "t" values of 6.616 and 6.389 resulted when the mean of section 2 (0.9433) was tested against those of sections 1 and 3 (0.9626 and 0.9672 respectively). These results indicate shortcomings in the sampling technique used, but since the precaution had been taken to obtain all samples from the middle section (see page 7), the diameter measurements from the different ovaries are comparable.

Distribution of eggs in right and left ovaries

Another preliminary step in the investgiation was to examine possible differences between the size distributions of the eggs in the right and left members of a pair of ovaries. Samples were taken from both ovaries of a pair (no. 21) according to the sampling procedure described below. Measurements were made of all eggs with diameters greater than 0.143 mm. and recorded in table 5. This lower limit was arbitrarily picked to avoid measuring the tremendous number of smaller eggs. The frequency distributions for the right and left ovaries were compared by a chi-square test (Snedecor 1946, pp. 205-207). The result, a chi-square of 24.411 (P = 0.6, 27 d.f.[2/]), leads to the conclusion that differences between the frequency distributions of egg diameters for the right and left ovaries of the same pair are negligible.

2/ The last three classes were combined because of their low frequencies.

Table 5.--Frequencies of egg diameters of right and left ovaries from the same fish

Class midpoint		Frequency	
(micrometer units*)	(mm.)	Right ovary	Left ovary
7	0.154	341	393
8	0.176	256	233
9	0.198	203	214
10	0.220	158	170
11	0.242	124	114
12	0.264	105	95
13	0.286	99	96
14	0.308	85	83
15	0.330	65	73
16	0.352	69	62
17	0.374	76	69
18	0.396	70	76
19	0.418	75	95
20	0.440	84	68
21	0.462	32	49
22	0.484	23	22
23	0.506	5	12
24	0.528	3	2
25	0.550	3	3
26	0.572	6	5
27	0.594	15	7
28	0.616	30	20
29	0.638	20	26
30	0.660	16	23
31	0.682	11	9
32	0.704	3	7
33	0.726	4	4
34	0.748	5	4
35	0.770	0	0
36	0.792	0	2
Sum		1986	2036

* 1 micrometer unit = 0.022 mm.

Description of sampling procedure

The following procedure was used in sampling the ovaries for egg diameter measurements. It should be pointed out that the difference of means anterio-posteriorly was not inspected when this procedure was chosen. (1) A cross section about 1/4 inch thick was taken from an ovary (always from the middle and from the left ovary, whenever possible, for the sake of uniformity). (2) The ovary wall and the projections of this wall into the lumen were removed. (3) The section was placed in an 8-ounce jar about two-thirds full of 10-percent formalin and shaken in an agitator. (4) The contents of the jar were then stirred with a metal tube which had an inner diameter of 12 mm. An erratic motion was used so that the eggs would not move in circular stream. (5) The tube was then quickly lifted out of the jar and vertically plunged back. (6) The top of the tube was closed tightly with the thumb, and tube and contents were withdrawn. (7) Steps 4 through 6 were repeated several times. (8) The samples thus obtained were combined and broken down further by teasing. (9) A subsample was taken by means of a medicine dropper with an opening of 2.5 mm. at the mouth. (10) The eggs in this subsample were measured to the nearest 0.022 mm. under a dissecting microscope.

MODES IN THE FREQUENCY DISTRIBUTION OF EGG DIAMETERS

To investigate the complete frequency distribution of egg sizes in the ovary, all the eggs in a sample from the ripest-appearing ovary from the central equatorial Pacific (no. 57) were measured. The measurements included the follicular cells, as no sharp line of demarcation exists between these and small ova. To augment the portion of the frequency distribution representing the larger eggs, a second, larger sample was taken and only eggs with diameters greater than 0.165 mm. were measured. Samples 1 and 2 (table 6) were combined and smoothed twice by a moving average of three to produce the frequency distribution shown in figure 1. In combining the samples an adjustment of sample 2 had to be made to account for eggs smaller than 0.165 mm. which had not been counted. The number of eggs in sample 2 was about 1.5 times the number of eggs over 0.165 mm. in sample 1. It was assumed large and small eggs were present in the same proportion in both samples. Hence the smaller classes of sample 2 were estimated as 1.5 times the same classes of sample 1. Besides the prominent mode resulting from the tremendous number of primitive eggs, two modes of maturing eggs (and possibly a third at 0.38 mm.) are evident.

Table 6.--Frequencies of egg diameters of most mature ovaries from Hawaiian area, western equatorial Pacific, and central equatorial Pacific

Class midpoint		Central Pacific		Western Pacific	Hawaiian area
(micrometer units)	(mm.)	Sample 1	Sample 2		
1	0.022	228	-	-	-
2	0.044	1598	-	-	-
3	0.066	2481	-	-	-
4	0.088	2249	-	-	-
5	0.110	1698	-	-	-
6	0.132	816	-	255	217
7	0.154	363	-	148	168
8	0.176	166	193	88	91
9	0.198	119	110	65	51
10	0.220	71	89	42	18
11	0.242	60	82	39	20
12	0.264	42	77	29	23
13	0.286	31	44	26	21
14	0.308	18	38	34	14
15	0.330	10	35	27	8
16	0.352	8	25	26	14
17	0.374	14	22	35	9
18	0.396	11	25	23	8
19	0.418	11	15	13	14
20	0.440	6	9	23	7
21	0.462	4	13	13	9
22	0.484	5	10	21	6
23	0.506	3	6	20	10
24	0.528	3	9	22	3
25	0.550	5	12	16	6
26	0.572	1	11	10	6
27	0.594	2	14	11	8
28	0.616	5	18	4	6
29	0.638	3	13	1	8
30	0.660	3	16	0	15

Table 6.--Frequencies of egg diameters of most mature ovaries from Hawaiian area, western equatorial Pacific, and central equatorial Pacific - Continued

Class midpoint		Central Pacific		Western Pacific	Hawaiian area
(micrometer units)	(mm.)	Sample 1	Sample 2		
31	0.682	7	11	0	6
32	0.704	2	5	0	8
33	0.726	3	4	1	4
34	0.748	0	4	1	2
35	0.770	0	5	0	4
36	0.792	1	3	3	1
37	0.814	1	0	5	-
38	0.836	0	0	9	-
39	0.858	0	1	7	-
40	0.880	0	1	6	-
41	0.902	0	1	10	-
42	0.924	0	2	6	-
43	0.946	0	3	14	-
44	0.968	2	1	13	-
45	0.990	3	1	9	-
46	1.012	4	11	7	-
47	1.034	3	4	6	-
48	1.056	1	10	2	-
49	1.078	1	4	0	-
50	1.100	1	2	1	-
51	1.122	0	5	0	-
52	1.144	1	5	1	-
53	1.166	-	4	1	-
54	1.188	-	0	-	-
55	1.210	-	5	-	-
56	1.232	-	2	-	-
57	1.254	-	0	-	-
58	1.276	-	0	-	-
59	1.298	-	1	-	-
Sum		10064	981	1093	785

For comparative purposes the ripest-appearing ovaries from the Hawaiian area (no. B472) and the western equatorial Pacific (no. 1002) were also selected for detailed study. The numerous eggs smaller than 0.121 mm. were excluded, however, since ovary no. 57 had already provided information about this part of the frequency distribution. The smoothed frequency distribution of egg diameters of the ovary from the western equatorial Pacific (fig. 2) shows three definite groups of maturing eggs at 0.35 mm., 0.51 mm., and 0.98 mm. The ovary from the Hawaiian area (fig. 2) shows a definite last mode at 0.66 mm., which is a position below those of the last modes of the ovaries of the other two areas. Two more modes of maturing eggs are suggested at 0.29 mm. and 0.40 mm. The fact that these two suspected modes are at positions slightly to the left of comparable but better defined modes in more mature ovaries strengthens the possibility that they are real.

RELATION OF RELATIVE OVARY WEIGHT TO DEGREE OF RIPENESS

In order to determine more accurately the position of the final mode in the size frequency distribution of eggs for all ovaries, systematic measuring of ova representing that mode was begun. Whenever the group of largest eggs was not distinguishable from the rest of the eggs by its physical characteristics, measuring was started with eggs which were considered small

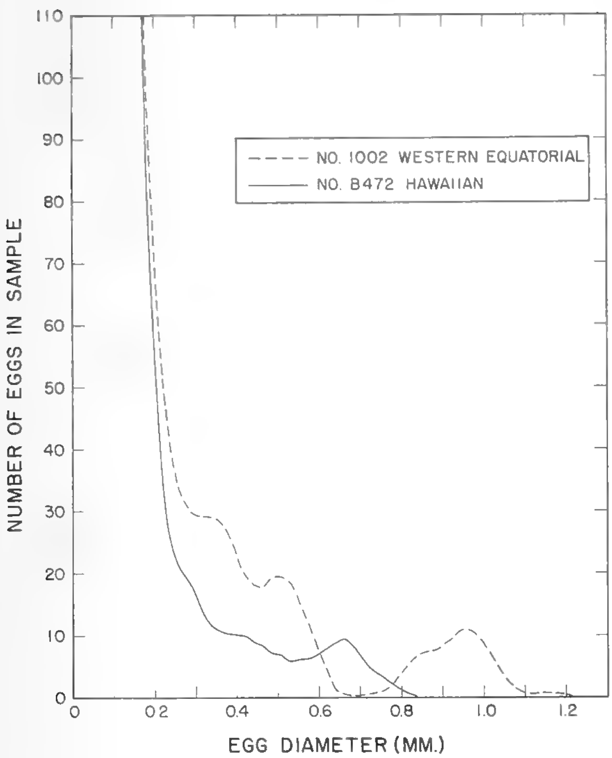

Figure 2.--Egg diameter frequencies from ripest ovaries of Hawaiian and western equatorial Pacific areas.

enough to be definitely outside the lower limits of the group. The resulting frequency distribution was then smoothed twice by a moving average of three and plotted. The descending slope of the second to the last group of eggs of this plot was then extended by eye. The amount under this extension at each size class was subtracted from the total at that size to get the ascending slope of the most mature group and its mode. This is illustrated in figure 3. By experimentally shifting the extension to the right and left to its apparent limits, the mode was shifted 0.04 mm. at the very most. If the shift was too much to the left, the frequency distribution of the largest group of eggs would become bimodal. Overshifting to the right had very little effect in the position of the mode.

After 33 ovaries from the central equatorial Pacific had thus been investigated, a relation between modal position and relative ovary weight (ovary weight/fish weight) was sought. The diameter frequencies of the samples from these ovaries are listed in table 7 with asterisks (*) marking the modal positions. As shown in figure 4, the relation between modal diameter and relative ovary weight appears to be curvilinear. To determine the best mathematical relation, three regression lines were fitted to the data. The modal diameter[3] and the relative ovary weight x 103[4] were used as the variates for one line; modal diameter and the logarithm of the relative ovary weight were variates for another; and logarithms for both modal diameter and relative ovary weight were variates for the third line. The sums of squares of deviation from these lines were 3396.91, 788.35, and 878.85 respectively. The line of best fit, the semi-logarithmic relation, may be described by the equation:

$$\hat{Y} = 0.7055\ X - 0.1478$$

where $\hat{Y}$ is the modal diameter in millimeters and X is the log (relative ovary weight). The regression coefficient ($b = 0.7055$) differs significantly from 0 ($t = 9.965$, $P < 0.001$). The correlation coefficient ($r = 0.88$) is also highly significant ($P < 0.01$).

Positions of the last mode for six ovaries from the western equatorial area were examined to determine if the same relation held for the two areas. The six ovaries were selected to cover the range of logarithms of relative ovary weights. The frequency distributions are tabulated in table 8. The regression of modal diameter on log (relative ovary weight) was calculated, yielding the equation:

$$\hat{Y} = 0.6178\ X - 0.0597$$

The symbolism is the same as that in the previous paragraph.

---

[3] Coded by using micrometer units. One micrometer unit = 0.022 mm.

[4] Called hereafter simply "relative ovary weight".

amete

	54	55	56	57	58	59	60	61	62	Sum
8	0.188	1.210	1.232	1.254	1.276	1.298	1.320	1.342	1.364	
*	[illegible]	-	-	-	-	-	-	-	-	280
		-	-	-	-	-	-	-	-	96
		-	-	-	-	-	-	-	-	226
		-	-	-	-	-	-	-	-	310
		-	-	-	-	-	-	-	-	63
		-	-	-	-	-	-	-	-	183
		-	-	-	-	-	-	-	-	122
		-	-	-	-	-	-	-	-	179
		-	-	-	-	-	-	-	-	111
		-	-	-	-	-	-	-	-	141
		-	-	-	-	-	-	-	-	199
		-	-	-	-	-	-	-	-	396
		-	-	-	-	-	-	-	-	588
		-	-	-	-	-	-	-	-	134
		-	-	-	-	-	-	-	-	350
		-	-	-	-	-	-	-	-	207
		-	-	-	-	-	-	-	-	91
		-	-	-	-	-	-	-	-	704
		-	-	-	-	-	-	-	-	460
		-	-	-	-	-	-	-	-	429
		-	-	-	-	-	-	-	-	598
		-	-	-	-	-	-	-	-	503
		-	-	-	-	-	-	-	-	323
		-	-	-	-	-	-	-	-	321
		-	-	-	-	-	-	-	-	103
	[illegible]	1	1	-	-	-	-	-	-	110
		-	-	-	-	-	-	-	-	176
		-	-	-	-	-	-	-	-	339
	[illegible]	6	2	2	1	1	0	0	1	224
		-	-	-	-	-	-	-	-	152
		-	-	-	-	-	-	-	-	119
		-	-	-	-	-	-	-	-	436
		-	-	-	-	-	-	-	-	369

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Table 7.--Frequencies of egg diameters for ovaries from the central equatorial Pacific showing position of mode of most mature group

Ovary number	Class midpoint																																																									Sum
	6[1]	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	
	0.132[2]	0.154	0.176	0.198	0.220	0.242	0.264	0.286	0.308	0.330	0.352	0.374	0.396	0.418	0.440	0.462	0.484	0.506	0.528	0.550	0.572	0.594	0.616	0.638	0.660	0.682	0.704	0.726	0.748	0.770	0.792	0.814	0.836	0.858	0.880	0.902	0.924	0.946	0.968	0.990	1.012	1.034	1.056	1.078	1.100	1.122	1.144	1.166	1.188	1.210	1.232	1.254	1.276	1.298	1.320	1.342	1.364	
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	35	25	10	13	20	29	39•	28	29	10	3	6	0	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	280
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	2	8	12	10	15•	15	11	8	6	4	1	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	96
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	13	14	17	19	12	12	7	7	8	7	18	23•	13	16	13	4	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	226
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	12	20	23	20	17	23	20	17	9	13	17	24	18	17•	17	8	6	7	1	1	1	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	310
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	2	4	6	6	9•	10	6	4	5	4	1	1	0	0	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	63
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	8	4	22	25	25•	33	20	19	12	7	5	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	183
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	0	2	4	7	13	17	18•	20	8	8	9	7	4	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	122
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	21	11	10	10	8	13	17	17•	18	10	6	9	2	3	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	179
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	5	9	8	20	25•	15	10	7	6	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	111
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	2	4	5	14	15	17•	18	15	12	15	11	6	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	141
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	2	0	0	6	7	13	18	19	29	25•	23	19	13	11	5	4	3	0	0	1	-	-	-	-	-	-	-	-	-	-	199
23	-	-	-	-	-	-	-	-	-	21	15	17	16	21	26	26	24	35	35•	29	29	32	15	21	10	8	7	1	5	1	0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	396
27	-	-	-	-	-	-	-	-	-	114	71	54	46	43	29	31	24	20	29	30•	27	16	16	15	7	8	4	2	0	0	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	588
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	4	5	15	18	18•	20	18	11	7	6	1	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	134
32	-	-	-	-	-	-	-	-	-	15	16	19	22	20	24	23	24	12	23	16	23	27•	20	14	14	11	8	8	6	1	2	1	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	350
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	4	13	21	24	21	26•	19	22	19	11	10	9	0	3	1	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	207
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	3	6	9	9	13	12•	13	8	3	5	5	2	0	0	1	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	91
36	-	-	152	132	98	67	47	32	25	23•	19	9	10	15	14	12	10	7	3	8	3	5	3	3	3	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	704
37	-	-	-	-	118	75	60	45	29	16	14	20	16	10	4	7	7	10	7	7	6	4	0	3	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	460
38	-	-	-	-	71	52	34	25	23	12	5	9	8	9	3	10	14	18	21	19	24•	26	15	11	8	6	3	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	429
41	14	71	101	106•	77	65	57	37	30	16	15	5	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	598
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47	90	77	48	26	22	30•	20	6	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	321
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	2	7	11	8	16	12	16•	11	9	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	103
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	1	1	5	5	10	13	17•	15	12	6	6	5	6	2	0	0	1	1	-	-	-	-	-	-	110
52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	3	6	7	20	24	27	14	21•	19	12	7	4	3	3	3	0	1	-	-	-	-	-	-	-	-	-	-	176
55	-	-	-	-	-	-	-	-	51	36	41	25	17	16	14	13	6	11	15	13	19•	10	12	15	9	7	4	2	1	0	1	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	339
56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	5	5	4	8	9	15	25	24	21	28•	23	22	6	8	6	6	2	2	1	1	0	0	1	224
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1	3	9	12	13	21	21•	18	17	11	4	7	4	3	2	0	1	0	1	-	-	-	-	-	-	-	-	-	-	-	152
62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	3	9	6	11	16	20•	23	16	6	3	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	119
64	-	-	48	64	54	39	40	30	24	21	26	21	20•	17	17	8	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	436
65	-	-	59	44	33	26	32	12	17	23	22•	20	20	20	14	10	10	5	0	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	369

1/ Micrometer units

2/ Millimeter

• Position of mode

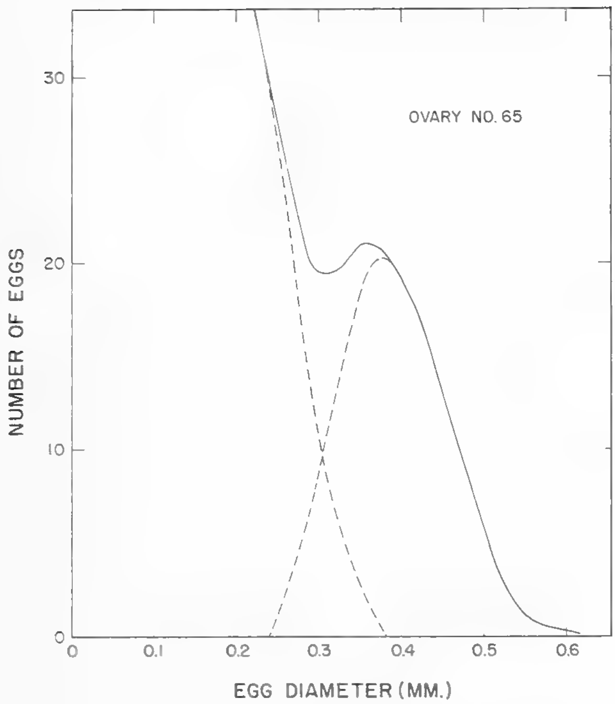

Figure 3.--Method of determining position of mode.

The data for the two regions were compared by the analysis of covariance (Snedecor 1946, pp. 318-321). The results (table 9) showed that the differences between them were so small that the data could be considered together. Combining the data from both regions resulted in the following equation of regression:

$$\hat{Y} = 0.6935\ X - 0.1367$$

In order to determine at what level of relative ovary weight the eggs first show signs of maturing, i. e. begin to turn opaque, all central and western equatorial Pacific ovaries with relative ovary weights smaller than 7 were sampled and investigated for opaque eggs. Randomly picked ovaries from the first year of collection in the Hawaiian area were also investigated. These are noted in the tables in the appendix. The few ovaries with a relative ovary weight of 2 were all immature. Only 11 percent of the ovaries with a relative ovary weight of 3 had eggs in the early maturing stage, whereas 65 percent of those with a relative ovary weight of 4 had such eggs.

The possibility of using the relative ovary weight as a tool for measuring the ripeness of a fish easily and objectively now arises. The size of the egg at the different stages of ripeness is known (page 2). This size may be predicted from the relative ovary weight. Thus, by using the regression of modal diameter on relative ovary size, relative ovary weight values were assigned to the different classes of ripeness as follows: 0 to 3 are considered immature, 4 to 18 early maturing, 19 to 28 late maturing, and larger than 28 mature. Spent fish are not recognized by this method, being classified in the stage of maturity which represents the most advanced of the remaining groups of eggs.

A certain amount of error is involved in classifying the degree of ripeness using relative ovary weights. This error was estimated by: (1) calculating the probabilities of sampling a fish in the immature stage and classifying it as immature, early maturing, late maturing, and mature; of sampling a fish in the early maturing stage and classifying it as immature, early maturing, late maturing, and mature; etc. (Pearson 1931, tables VIII and IX); (2) calculating a percentage of error for each category based on these probabilities (see below). The probabilities (table 10) are based on a theoretical population of which the 33 ovaries used for the regression line for the central equatorial Pacific (page 10) constitute a sample. The ovaries involved in the regression computations of the western equatorial Pacific were not used as these had been selected not randomly but according to their relative ovary weights.

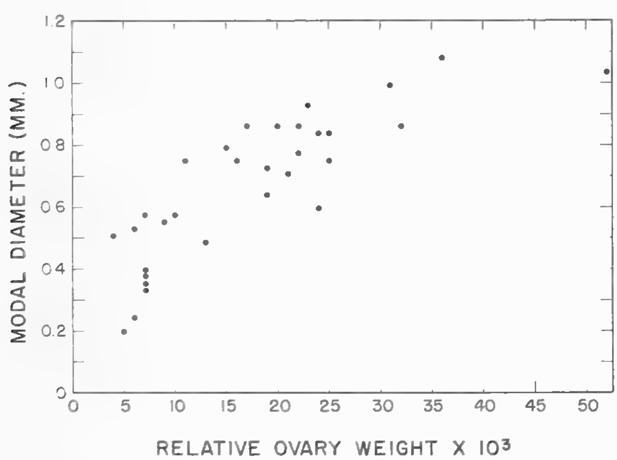

Figure 4.--Relation of modal diameter to relative ovary weight.

If the probability of an individual fish actually being in the stage of ripeness in

Table 8.--Frequencies of egg diameters for ovaries from the western equatorial Pacific showing position of mode of most mature group

Class midpoint		Ovary number					
(micrometer units)	(mm.)	1019	1029	1039	1065	1081	1092
10	0.220	-	-	-	37	43	-
11	0.242	-	-	-	32	42	-
12	0.264	-	-	-	42	34	-
13	0.286	-	-	-	30	34	-
14	0.308	-	-	36	24	20	-
15	0.330	-	23	30	16	21	-
16	0.352	-	27	27	21	22	-
17	0.374	-	25	15	13	17	-
18	0.396	-	30	10	10	16	-
19	0.418	-	23	17	13	15	-
20	0.440	-	23	20	9	14	-
21	0.462	-	25	12	6	12	-
22	0.484	-	23	11	7	12	-
23	0.506	-	27	13	18*	15	-
24	0.528	-	22	21	9	13	-
25	0.550	-	25	13	10	16	-
26	0.572	-	21	24*	4	18*	-
27	0.594	-	11	17	13	11	-
28	0.616	-	12	15	5	6	-
29	0.638	-	17	18	5	7	-
30	0.660	-	16	8	7	2	-
31	0.682	-	20	5	5	1	-
32	0.704	2	13*	2	1	-	1
33	0.726	0	13	2	1	-	2
34	0.748	1	9	2	-	-	5
35	0.770	1	7	1	-	-	7
36	0.792	3	4	1	-	-	16
37	0.814	6	1	-	-	-	18
38	0.836	11	1	-	-	-	24
39	0.858	18	-	-	-	-	23*
40	0.880	13	-	-	-	-	24
41	0.902	20	-	-	-	-	25
42	0.924	16	-	-	-	-	15
43	0.946	16	-	-	-	-	7
44	0.968	26*	-	-	-	-	8
45	0.990	18	-	-	-	-	3
46	1.012	14	-	-	-	-	2
47	1.034	12	-	-	-	-	1
48	1.056	9	-	-	-	-	-
49	1.078	2	-	-	-	-	-
50	1.100	0	-	-	-	-	-
51	1.122	2	-	-	-	-	-
52	1.144	1	-	-	-	-	-
Sum		191	418	320	338	391	181

* Position of mode

Table 9.--Analysis of covariance of largest modal diameter on relative ovary weight regressions for the western and central equatorial Pacific

Source	Degrees of freedom	Errors of estimate	
		Sum of squares	Mean squares
Between regions	1	3.195	3.195[1/]
Within regions	35	879.430	25.127
Total	36	882.625	

[1/] This unusually low figure is suspect, but recomputation has shown it to be correct.

Table 10.--Probabilities of ovaries occurring in various stages of maturity using two methods of classification

Classification by modal diameters	Classification by relative ovary weights				
	Immature	Early maturing	Late maturing	Mature	Sums
Immature	.009	.008	.000	.000	.017
Early maturing	.006	.547	.060	.016	.629
Late maturing	.000	.057	.074	.025	.156
Mature	.000	.015	.061	.122	.198
Sums	.015	.627	.195	.163	1.000

which it is placed is considered, this method of classification results in considerable error, especially in stages where the range of egg sizes is small, such as the late maturing stage. Only 38 percent of the fish classified as late maturing would actually be in the late maturing stage. In the early maturing stage, however, which has a large range of egg sizes, 87 percent of the fish would be correctly classified.

This error in classifying individual fish does not invalidate the method for use in group statistics, as the number of fish lost to one stage due to misclassification is somewhat balanced by the number of fish gained by that stage due to misclassification in the opposite direction; e.g., the number of immature fish classified as early maturing is somewhat balanced by the number of early maturing fish classified as immature. The calculated percentage of error mentioned earlier represents the error in the number placed in each group. The expected number in a group resulting from classification by relative ovary weights is either lower or higher than the expected number actually in the group. The amounts and the direction of error are 11.8 percent too low for the immature group, 0.3 percent too low for the early maturing group, 25.0 percent too high for the late maturing group, and 17.7 percent too low for the mature group. An example of the way these percentages were arrived at follows: the probabilities of classifying a fish in the immature stage according to relative ovary weights are 15 in a thousand (sum of column labelled immature, table 10); the probabilities of a fish actually being immature are 17 in a thousand (sum of row labelled immature); the error is 2/17 or 11.8 percent.

Since the amount of material was too small for quantitative procedures in those aspects of the study which consider the stage of ripeness, the use of relative ovary weights as a measure of ripeness was thought to be justified.

SIZE AT FIRST SPAWNING

If fish sizes are plotted against stages of maturity, the size at first spawning should become evident. Although fish larger than the size at first spawning could be in any stage of maturity, those below this size would all be immature. A plot of this type was made (fig. 5) using fish weight and relative ovary weight as measures of size and maturity respectively.

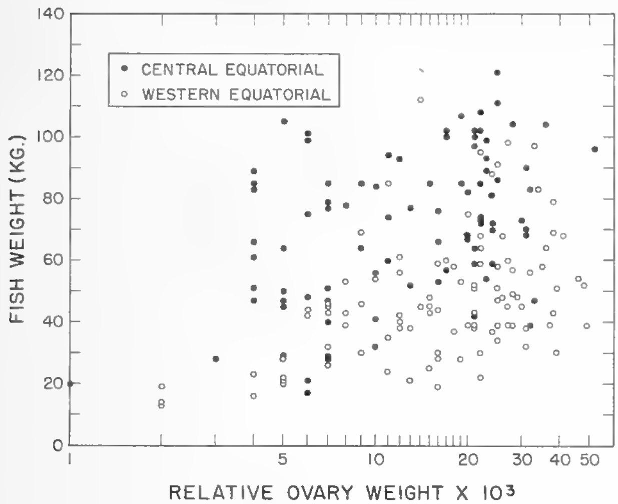

Figure 5.--Plot of fish weight against relative ovary weight.

In this plot the maturing fish (those having relative ovary weights of 4 or greater) were almost all over 20 kg. (44 lbs.) while four of the five immature fish (those having relative ovary weights of 3 or less) weighed less. The number of fish below 20 kg., is insufficient to set more definitely the size at first spawning.

Data from the equatorial Pacific and the Hawaiian area are contradictory as to what happens in the ovaries after spawning. Figure 5 indicates that once a fish spawns its ovaries never revert to the immature stage of having only primitive eggs. This is shown by the fact that, with one exception, none of the relative ovary weights of fish greater than 20 kg. were less than 4. Many fish weighing as much as 100 kg. (220 lbs.) from Hawaiian waters were immature according to their relative ovary weights.

Since there were relatively few fish of 20 kg. and under, the ovaries of these fish were subjected to further study in an effort to find indications of past spawning, such as residual eggs. Although the absence of these eggs would not necessarily mean that spawning had not taken place, as they might have been completely reabsorbed, their presence would mean that spawning had occurred. Five of the seven ovaries examined did not have residual eggs. Only two fish of 14 and 17 kg. (31 and 37 lbs.) did have residual eggs. The size at first spawning, therefore, ranges from 14 kilograms (possibly less) to 20 kilograms. This agrees with Kikawa (1953), who stated that the size at first spawning is roughly 90 to 100 cm. This corresponds to fish of 16 to 21 kg. (see table B, footnote 3).

Moore (1951), working on the age and growth of the yellowfin in the Hawaiian fishery, estimated that the yellowfin grows from a weight of 7 to a weight of 46 pounds (3 to 20 kg.) in its second year of growth. If the bigeye, which weighs slightly more than yellowfin of comparable lengths and attains a greater size, can be assumed to have a growth rate of this magnitude in its early years, the range of size variation within a year class could include individuals of 14 and 20 kg. Only a greater sampling of fish in the lower size range and a study of age and growth, however, will definitely answer the question of age of sexual maturity.

TEMPORAL AND SPATIAL DISTRIBUTION OF RIPE OVARIES

Positions of capture of bigeye in the late maturing and mature stages (fig. 6) show that these fish are widely scattered in the equatorial regions. Kikawa (1953) who worked in the western equatorial Pacific also found this to be true but with an apparent concentration in the Keats Bank area ($5^{\circ}53.8'$N., $173^{\circ}29.4'$E.).

Although ovaries in the late maturing and mature stages were obtained 400 miles to the southeast of Hawaii at 14°N., 150°W., they were completely absent among the 503 of the Hawaiian collection.

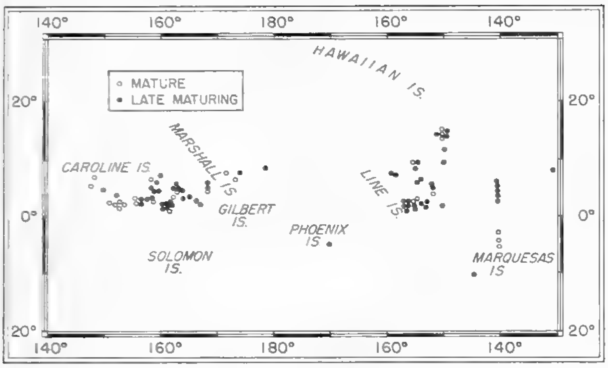

Figure 6.--Locations of capture of bigeye in late maturing and mature stages.

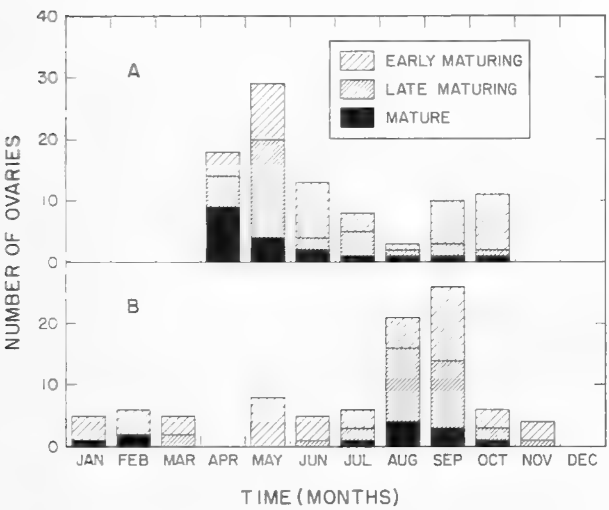

Figure 7.--Plot of numbers of bigeye at various stages of maturity against time. A - bigeye from the western Pacific; B - bigeye from the central Pacific.

The numbers of fish in the different stages of maturity are shown for each month for each equatorial area (fig. 7). The separation into stages was done according to the relative ovary weights. All fish under 20 kg. or with relative ovary weights of less than 4 were judged to be sexually immature and were omitted.

Mature fish were found throughout the period of collection, April through October, in the western equatorial Pacific (fig. 7A). This lengthens the known period of occurrence of mature fish in this area. Shimada (1951) and Kikawa (1953) had previously found mature bigeye from June to September and June to August, the periods to which their collections were limited.

The data from the central equatorial Pacific suggest two separate spawning periods, one in January and February and the other from July to October (fig. 7B). This cannot be accepted as a firm conclusion, however, because of the small number of samples per month and the lack of data in April, the month of apparently greatest spawning activity in the western equatorial area.

Data from the Hawaiian area show a more definite but somewhat different picture. Relative ovary weight frequencies for each month (fig. 8) reveal an increase of relative ovary weights from winter to summer. The monthly mean modal diameters (table 11) calculated from the equation $\hat{Y} = 0.6935\ X - 0.1367$ (see page 13) show a definite seasonal increase when plotted against time (fig. 9). The mean diameter at the peak month of June, however, is far below that expected of a spawning population. It is interesting to note here that the commercial catch of bigeye in Hawaii is at its annual minimum during the summer (Otsu 1954). The cessation of mean modal diameter increase in June coupled with the low summer catches suggests that maturing bigeye in Hawaiian waters leave before they are mature. The possibility of their being present but not biting can be ruled out by the fact that they do bite on the same type of gear in equatorial waters.

TYPE OF SPAWNING

If one looks at the frequency distributions of egg diameters of the entire ovary (figs. 1 and 2), several modes of maturing eggs are seen. These modes could represent either groups of eggs that will be spawned in one season or groups of eggs that will be spawned in succeeding seasons, depending upon the rate of growth of the egg. It was intended at first to find the growth rate of the maturing egg and thus find out whether the modes of the smaller maturing eggs could advance to the position of the mature eggs within the length of the spawning season. This plan had to be abandoned when it proved impossible to define the spawning season with the available data.

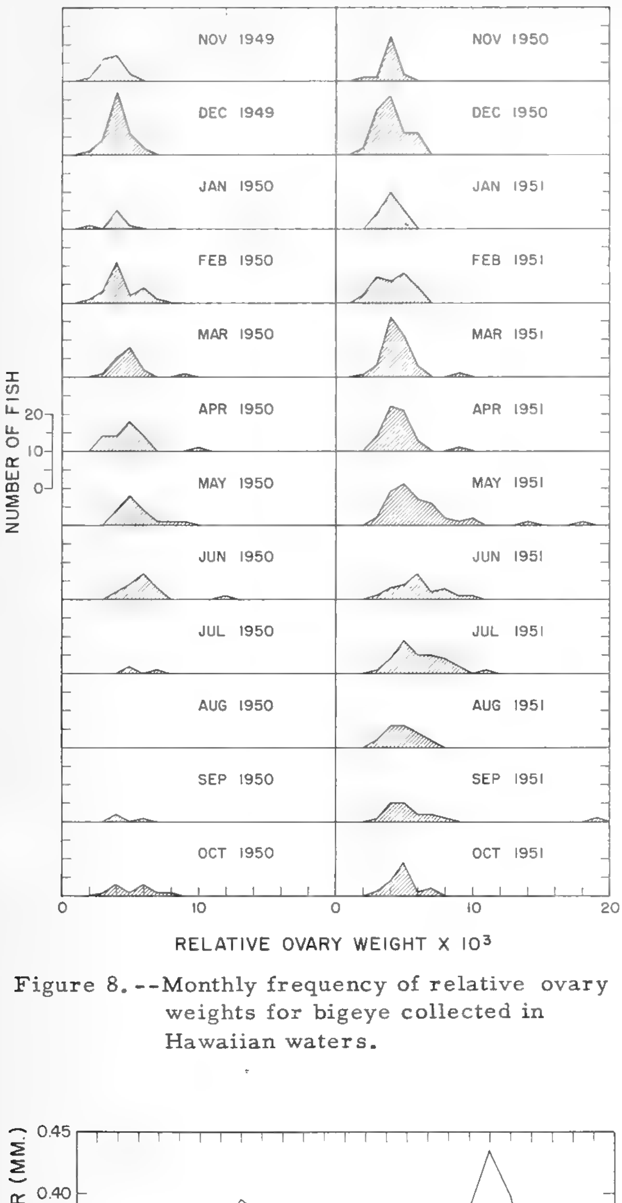

Figure 8.--Monthly frequency of relative ovary weights for bigeye collected in Hawaiian waters.

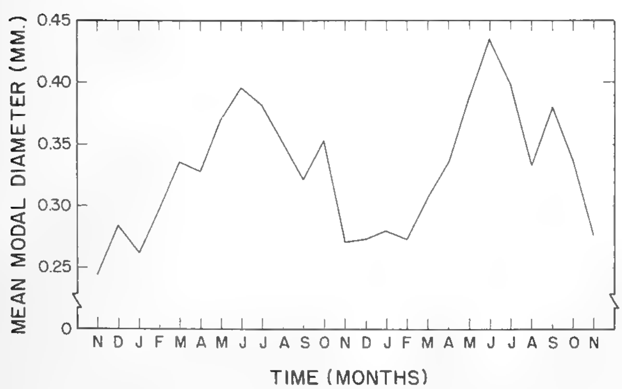

Figure 9.--Plot of mean modal diameter against time for bigeye of Hawaiian waters.

From observations on residual eggs, fractional spawning is strongly suspected. The frequency of occurrence of randomly selected ovaries with no residual eggs, with residual eggs in the early stages of reabsorption (characterized by the presence of an oil globule, the still tough outer membrane, and translucence), or with residual eggs in the late stages of reabsorption (eggs which were opaque, small, and dark) was observed. Of the 121 ovaries examined, 60 had no residual eggs, 13 had eggs in the early stages of reabsorption, and 48 had eggs in the late stages of reabsorption. The small number of ovaries with eggs in the early stages (10.7 percent) indicates that residual eggs are not long in this stage; yet four ovaries had residual eggs in early stages of reabsorption together with developing eggs in the late maturing or mature stages. This fact indicates a possibility of at least two spawnings in close succession.

FECUNDITY

In selecting the ovaries for this study, the fish were arranged in the following weight classes: below 100 lb. (45.4 kg.), 100 lb. to 129 lb. (45.4 kg. to 58.7 kg.), 130 lb. to 159 lb. (58.7 kg. to 72.3 kg.), 160 lb. to 189 lb. (72.3 kg. to 86.0 kg.), 190 lb. to 219 lb. (86.0 kg. to 99.6 kg.), and over 220 lb. The ovaries from each class were then inspected and only those with maturing eggs easily distinguished from the smaller eggs were considered. From this group of ovaries an attempt was made to select at random two ovaries from each size class. In the two smallest groups, only one suitable ovary for each class was found.

Pie-sections were cut from transverse slices from the middle portion of the ovary and weighed immediately to the nearest .001 gram. The number in the most mature group of eggs in the section was then determined by actual count and multiplied by the ovary weight/sample weight to get an estimate of the number of maturing or maturing eggs in the ovary.

Estimates of the number of eggs per spawning (table 12) range from 2.9 million to 6.3 million. A plot of fecundity against fish weight (fig. 10) shows that larger fish tend to have more eggs per spawning with wide variations between fish of the same size. The relation between number of eggs spawned and fish weight appears to be curvilinear.

Table 11.--Monthly mean modal diameters for the Hawaiian area

Year	Month	Mean modal diameter (mm.)
1949	November	0.2437
	December	0.2839
1950	January	0.2620
	February	0.2966
	March	0.3361
	April	0.3281
	May	0.3693
	June	0.3961
	July	0.3818
	August	--
	September	0.3215
	October	0.3532
	November	0.2707
	December	0.2732
1951	January	0.2803
	February	0.2734
	March	0.3060
	April	0.3357
	May	0.3874
	June	0.4349
	July	0.3973
	August	0.3336
	September	0.3800
	October	0.3383
	November	0.2759

Table 12.--Data for estimations of the number of mature eggs in ovaries

Ovary number	Fish weight (kg.)	Ovary weight (gm.)	Sample weight (gm.)	Number of mature eggs in sample	Estimated number of mature eggs in pair of ovaries (millions)
2	76	1229	0.761	2429	3.9
3	102	2130	2.301	6842	6.3
8	91	2217	1.969	3943	4.4
12	107	2048	1.527	3086	4.1
30	57	970	0.763	2409	2.9
31	72	1597	0.905	1863	3.3
48	85	993	1.579	6240	3.9
51	90	2818	2.456	2977	3.4
60	39	1268	1.353	3095	2.9
63	65	2351	2.677	3310	2.9

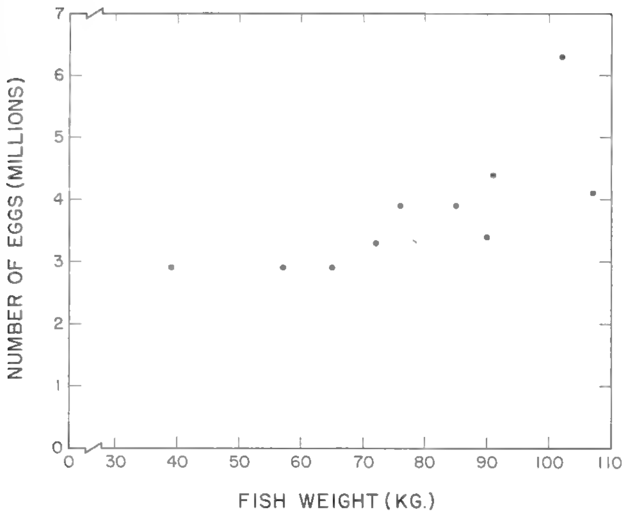

Figure 10.--Relation of number of eggs spawned to fish size.

SUMMARY

This study is based on examinations of the ovaries and the eggs within the ovaries of the bigeye tuna, Parathunnus sibi. Material collected from the western equatorial and central Pacific Ocean was used.

Investigations were made of egg diameter distributions in the ovaries to determine sampling procedures and the following findings resulted: (1) In a pair of ovaries the distribution of egg diameters in the right member is the same as the distribution in the left member; (2) eggs of the most mature group in an ovary are evenly distributed throughout the ovary; and (3) the variance of diameters of mature eggs is least at the periphery and the posterior of the ovary.

Frequency distributions of egg diameters of maturing and mature ovaries were multimodal. The most evident modes were those of the undeveloped and the most mature groups of eggs. There were suggestions of as many as two modes of maturing groups between these. The ovary weight relative to the fish weight was found to be associated with the mode of the most mature group of eggs in the ovary. The equation best describing the relation was calculated: $\hat{Y} = 0.6935\ X - 0.1367$ where $\hat{Y}$ is the modal diameter in millimeters and X is the ovary weight x 10^3/fish weight.

Indications of bigeye spawning were found in the western equatorial Pacific, the central equatorial Pacific, and locations 400 miles southeast of Hawaii, but none were found in Hawaiian waters.

The extent of the spawning season could not be determined with certainty. Bigeye in advanced stages of ripeness were caught in the central equatorial Pacific in January, February, July, August, September, and October. In the western equatorial Pacific fish near spawning were taken from April through October. Evidence of more than one spawning per season was found.

The size at which the bigeye first spawns was found to be about 14 to 20 kg.

The number of eggs extruded per spawning ranges from 2.9 to 6.3 million and depends roughly on the size of the fish.

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APPENDIX

Data on Ovaries Collected

Table A. --Data on ovaries collected in Hawaiian waters

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B1	88	424	11/22/49	5	B49[2/]	72	281	1/6/50	4
B2	81	313	Do.	4	B50[2/]	76	301	Do.	4
B3	87	267	Do.	3	B51	75	270	1/26/50	4
B4	91	211	Do.	2	B52[1/]	82	351	1/27/50	4
B5[2/]	70	245	Do.	4	B53[1/]	106	530	Do.	5
B6	40	125	11/23/49	3	B54	62	219	2/1/50	4
B7[1/]	98	429	11/25/49	4	B55[1/]	83	356	Do.	4
B8	62	249	Do.	4	B56	81	325	2/2/50	4
B9	60	222	Do.	4	B57	76	284	2/3/50	4
B10[2/]	57	175	11/28/49	3	B58	71	247	Do.	3
B11	54	254	Do.	5	B59	71	267	Do.	4
B12	88	368	Do.	4	B60[2/]	64	209	2/6/50	3
B13[2/]	62	208	Do.	3	B61	70	276	Do.	4
B14	64	205	Do.	3	B62	93	539	Do.	6
B15[2/]	67	230	11/30/49	3	B63	105	838	Do.	8
B16[1/]	66	242	Do.	4	B64	67	240	2/8/50	4
B17	64	230	12/5/49	4	B65[1/]	62	282	2/13/50	5
B18	102	369	Do.	4	B66	63	193	Do.	3
B19	69	287	Do.	4	B67	78	459	2/14/50	6
B20[1/]	88	563	Do.	6	B68	59	258	Do.	4
B21	66	219	12/6/49	3	B69	83	367	2/16/50	4
B22	65	356	Do.	5	B70[1/]	83	458	Do.	6
B23	69	374	12/8/49	5	B71	75	271	Do.	4
B24	100	443	Do.	4	B72	42	90	2/21/50	2
B25[2/]	87	340	Do.	4	B73	59	340	Do.	6
B26	93	535	Do.	6	B74	62	306	Do.	5
B27	60	232	Do.	4	B75[1/]	64	266	Do.	4
B28	61	182	12/9/49	3	B76	64	281	Do.	4
B29	94	369	Do.	4	B77	82	778	3/2/50	9
B30[2/]	63	242	Do.	4	B78	79	444	Do.	6
B31	75	295	12/15/49	4	B79	96	516	3/3/50	5
B32	75	409	Do.	5	B80[1/]	64	278	Do.	4
B33	77	390	Do.	5	B81	69	274	3/7/50	4
B34	72	315	12/16/49	4	B82	68	188	Do.	3
B35[1/]	96	440	12/20/49	5	B83	103	476	3/8/50	5
B36	52	192	Do.	4	B84[1/]	88	445	Do.	5
B37	101	331	12/21/49	3	B85[2/]	65	295	3/16/50	5
B38	73	314	Do.	4	B86	64	342	3/21/50	5
B39	48	114	12/22/49	2	B87	56	318	Do.	6
B40[2/]	66	237	Do.	4	B88	63	288	Do.	5
B41	78	326	Do.	4	B89[1/]	93	489	3/23/50	5
B42	85	306	12/23/49	4	B90[1/]	68	302	Do.	4
B43	90	410	12/27/49	5	B91	55	207	3/30/50	4
B44	65	283	Do.	4	B92	85	398	Do.	5
B45[2/]	59	228	12/30/49	4	B93	57	204	3/31/50	4
B46	85	244	Do.	3	B94	43	111	4/4/50	3
B47	21	32	1/6/50	2	B95[1/]	93	452	Do.	5
B48[1/]	58	209	Do.	4	B96	63	247	4/5/50	4

Table A. --Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B97	87	395	4/7/50	5	B149	90	442	6/20/50	5
B98[2/]	64	169	Do.	3	B150[1/]	64	768	6/21/50	12
B99	90	288	4/10/50	3	B151	70	303	6/22/50	4
B100[1/]	100	1137	4/11/50	11	B152[1/]	92	627	7/6/50	7
B101	94	478	Do.	5	B153[1/]	74	400	7/11/50	5
B102	53	238	Do.	4	B154[1/]	88	469	7/25/50	5
B103	69	210	4/13/50	3	B155	-	-	-	-
B104	51	235	4/14/50	5	B156[1/]	46	274	9/1/50	6
B105[1/]	53	299	4/18/50	6	B157[1/]	68	259	9/15/50	4
B106	56	240	4/20/50	4	B158[1/]	94	350	9/21/50	4
B107	73	326	Do.	4	B159	100	440	10/11/50	4
B108	60	339	4/21/50	6	B160[1/]	97	759	10/20/50	8
B109	95	407	Do.	5	B161[1/]	68	407	Do.	6
B110[2/]	58	266	4/27/50	5	B162	78	324	Do.	4
B111	104	642	4/28/50	6	B163	78	496	Do.	6
B112	73	371	Do.	5	B164[1/]	106	679	Do.	6
B113[1/]	67	338	Do.	5	B165[2/]	40	111	10/26/50	3
B114	59	333	Do.	6	B166	79	344	Do.	4
B115[1/]	74	280	5/2/50	4	B167	88	626	10/28/50	7
B116	73	318	Do.	4	B168	88	453	10/31/50	5
B117	60	353	Do.	6	B169	78	314	11/10/50	4
B118	100	633	5/4/50	6	B170[1/]	83	320	Do.	4
B119	77	542	Do.	7	B171	105	-	Do.	-
B120[1/]	76	354	5/9/50	5	B172	81	396	Do.	5
B121	65	278	Do.	4	B173	60	244	11/17/50	4
B122	60	351	Do.	6	B174	79	309	11/24/50	4
B123	86	458	5/12/50	5	B175[2/]	77	326	Do.	4
B124	71	381	Do.	5	B176	48	190	11/26/50	4
B125[1/]	82	446	5/18/50	5	B177	89	395	11/28/50	4
B126[1/]	68	324	Do.	5	B178	76	313	Do.	4
B127	61	357	Do.	6	B179	77	290	Do.	4
B128	58	266	Do.	5	B180	72	283	11/29/50	4
B129	66	318	5/19/50	5	B181	58	264	Do.	5
B130[1/]	70	391	5/23/50	6	B182	112	426	Do.	4
B131	59	315	Do.	5	B183	93	359	Do.	4
B132	76	689	5/25/50	9	B184	40	74	11/30/50	2
B133	81	670	5/26/50	8	B185[1/]	87	302	Do.	3
B134	67	239	Do.	4	B186	80	392	12/1/50	5
B135[1/]	84	298	6/2/50	4	B187	70	264	Do.	4
B136	63	378	Do.	6	B188	88	470	12/4/50	5
B137	61	314	Do.	5	B189	112	720	Do.	6
B138	69	326	6/13/50	5	B190[2/]	83	362	12/5/50	4
B139	77	471	Do.	6	B191	77	413	Do.	5
B140[1/]	76	503	Do.	7	B192	99	260	12/6/50	3
B141	73	352	Do.	5	B193	76	322	Do.	4
B142	65	363	Do.	6	B194	41	97	Do.	2
B143	83	472	6/14/50	6	B195[2/]	63	215	12/7/50	3
B144	50	320	Do.	6	B196	73	253	Do.	3
B145[1/]	89	662	6/16/50	7	B197	78	280	12/8/50	4
B146	55	323	6/18/50	6	B198	74	236	Do.	3
B147	76	440	Do.	6	B199	93	520	12/11/50	6
B148[1/]	79	575	6/20/50	7	B200	79	281	Do.	4

Table A. --Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B201	47	128	12/11/50	3	B253	69	323	2/7/51	5
B202	93	403	12/12/50	4	B254	43	258	Do.	4
B203	76	260	Do.	3	B255	37	85	Do.	2
B204	71	216	Do.	3	B256	73	336	Do.	5
B205	41	236	12/13/50	3	B257	74	255	Do.	3
B206	56	211	Do.	4	B258	41	103	Do.	3
B207	93	410	12/14/50	4	B259	50	125	Do.	2
B208	90	363	Do.	4	B260	79	441	2/9/51	6
B209	38	116	12/15/50	3	B261	76	401	Do.	5
B210	44	125	Do.	3	B262	80	262	Do.	3
B211	68	386	12/18/50	6	B263	55	311	2/14/51	6
B212	73	288	Do.	4	B264	79	360	Do.	5
B213	86	395	Do.	5	B265	68	297	Do.	4
B214	91	384	Do.	4	B266	52	169	Do.	3
B215	92	395	12/20/50	4	B267	91	350	Do.	4
B216	70	324	Do.	5	B268	103	633	2/15/51	6
B217	77	470	12/22/50	6	B269	53	169	2/20/51	3
B218	82	333	Do.	4	B270	75	293	Do.	4
B219	56	217	12/26/50	4	B271	54	192	Do.	4
B220	84	368	Do.	4	B272	35	103	Do.	3
B221	100	437	Do.	4	B273	77	438	Do.	6
B222	89	526	Do.	6	B274	36	111	2/28/51	3
B223	122	714	12/27/50	6	B275	72	321	3/7/51	4
B224	38	120	12/28/50	3	B276	71	285	Do.	4
B225	45	138	Do.	3	B277	56	247	Do.	4
B226	42	102	12/29/50	2	B278	90	297	3/9/51	5
B227	71	369	Do.	5	B279	43	157	Do.	4
B228	83	349	1/24/51	4	B280	78	384	Do.	5
B229	77	387	1/25/51	5	B281	77	332	3/12/51	4
B230	64	235	Do.	4	B282	37	88	Do.	2
B231	95	490	Do.	5	B283	41	110	3/13/51	3
B232	86	337	1/26/51	4	B284	68	36	Do.	5
B233	50	129	Do.	3	B285	88	396	3/14/51	4
B234	50	162	1/29/51	3	B286	80	349	Do.	4
B235	54	186	Do.	3	B287	51	208	3/15/51	4
B236	60	256	Do.	4	B288	69	331	Do.	5
B237	76	305	Do.	4	B289	78	363	Do.	5
B238	78	332	1/30/51	4	B290	71	289	3/19/51	4
B239	64	253	Do.	4	B291	92	805	Do.	9
B240	76	373	Do.	5	B292	66	307	Do.	5
B241	77	352	Do.	5	B293	86	492	Do.	6
B242	75	278	Do.	4	B294	70	294	3/20/51	4
B243	89	468	Do.	5	B295	55	251	Do.	5
B244	61	222	Do.	4	B296	89	375	3/21/51	4
B245	63	203	1/31/51	3	B297	77	384	Do.	5
B246	87	373	Do.	4	B298	64	269	3/22/51	4
B247	81	438	2/2/51	5	B299	47	163	Do.	3
B248	86	440	Do.	5	B300	72	265	3/26/51	4
B249	89	415	Do.	5	B301	81	389	Do.	5
B250	80	419	Do.	5	B302	85	386	Do.	5
B251	29	67	Do.	2	B303	72	294	Do.	4
B252	80	328	2/7/51	4	B304	65	226	Do.	3

Table A.--Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B305	88	485	3/26/51	6	B357	62	269	5/7/51	4
B306	76	282	3/27/51	4	B358	73	347	Do.	5
B307	36	135	Do.	4	B359	81	493	Do.	6
B308	85	479	Do.	6	B360	62	244	Do.	4
B309	66	359	3/29/51	5	B361	93	348	Do.	4
B310	77	550	4/2/51	7	B362	54	359	Do.	7
B311	65	269	Do.	4	B363	51	233	5/9/51	5
B312	114	885	4/3/51	8	B364	71	433	5/10/51	6
B313	97	490	Do.	5	B365	67	292	Do.	4
B314	98	560	Do.	6	B366	39	130	Do.	3
B315	54	225	4/4/51	4	B367	70	306	Do.	4
B316	41	115	Do.	3	B368	84	431	5/14/51	5
B317	23	6	Do.	0	B369	83	673	Do.	8
B318	103	477	4/5/51	5	B370	91	485	Do.	5
B319	77	266	Do.	3	B371	70	295	5/15/51	4
B320	45	286	Do.	6	B372	114	756	Do.	7
B321	46	169	Do.	4	B373	74	296	Do.	4
B322	63	338	4/10/51	5	B374	48	297	5/16/51	6
B323	81	441	Do.	5	B375	69	302	Do.	4
B324	51	322	Do.	6	B376	40	132	Do.	3
B325	78	485	Do.	6	B377	44	182	5/17/51	4
B326	50	238	4/11/51	5	B378	81	506	5/21/51	6
B327	91	346	Do.	4	B379	83	1140	Do.	14
B328	76	423	Do.	6	B380	83	412	Do.	5
B329	45	233	4/12/51	5	B381	97	687	Do.	7
B330	55	216	Do.	4	B382	96	1170	5/22/51	18
B331	87	371	4/16/51	4	B383	98	665	Do.	7
B332	72	279	Do.	4	B384	63	408	Do.	6
B333	62	272	4/17/51	4	B385	86	592	5/23/51	7
B334	70	286	Do.	4	B386	91	466	5/28/51	5
B335	76	333	4/18/51	4	B387	73	702	5/29/51	10
B336	72	379	4/19/51	5	B388	73	376	Do.	5
B337	64	297	Do.	5	B389	104	1065	5/31/51	10
B338	83	450	4/24/51	5	B390	68	556	Do.	8
B339	48	323	Do.	7	B391	79	567	Do.	7
B340	55	230	Do.	4	B392	82	323	6/6/51	4
B341	55	284	Do.	5	B393	76	733	Do.	10
B342	78	889	Do.	11	B394	87	515	Do.	6
B343	56	278	4/25/51	5	B395	70	534	Do.	8
B344	69	273	Do.	4	B396	101	565	6/7/51	6
B345	28	82	Do.	3	B397	57	467	Do.	8
B346	83	367	Do.	4	B398	58	286	Do.	5
B347	73	367	4/30/51	5	B399	43	119	Do.	3
B348	44	368	Do.	8	B400	54	320	Do.	6
B349	25	66	Do.	3	B401	79	512	Do.	6
B350	75	440	5/1/51	6	B402	73	575	Do.	8
B351	51	249	Do.	5	B403	43	206	6/13/51	5
B352	68	318	5/2/51	5	B404	76	473	Do.	6
B353	71	605	Do.	9	B405	78	452	6/18/51	6
B354	65	338	Do.	5	B406	45	210	Do.	5
B355	83	497	5/3/51	6	B407	53	188	6/21/51	4
B356	54	296	Do.	5	B408	88	541	6/25/51	6

Table A.--Data on ovaries collected in Hawaiian waters--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3	Ovary No.	Fish weight kg.	Ovary weight gm.	Date collected	Relative ovary weight x 10^3
B409	54	248	6/25/51	5	B457	72	336	8/28/51	5
B410	89	649	6/26/51	7	B458	53	227	Do.	4
B411	72	622	6/27/51	9	B459	85	341	Do.	4
B412	54	214	6/28/51	4	B460	54	280	8/29/51	5
B413	120	843	Do.	7	B461	73	369	8/30/51	5
B414	95	578	7/2/51	6	B462	57	225	8/31/51	4
B415	44	188	7/3/51	4	B463	63	325	Do.	5
B416	56	402	Do.	7	B464	85	626	Do.	7
B417	59	250	7/6/51	4	B465	50	244	9/4/51	5
B418	70	411	Do.	6	B466	69	381	9/5/51	6
B419	93	754	Do.	8	B467	78	364	9/7/51	5
B420	72	447	Do.	6	B468	57	194	Do.	3
B421	79	522	7/9/51	7	B469	83	304	Do.	4
B422	79	356	Do.	5	B470	98	579	9/11/51	6
B423	87	355	Do.	4	B471	88	871	9/17/51	10
B424	76	371	Do.	5	B472	88	1685	9/19/51	19
B425	94	396	Do.	4	B473	73	339	Do.	5
B426	71	335	Do.	5	B474	102	664	9/20/51	7
B427	74	382	Do.	5	B475	59	420	9/21/51	7
B428	84	743	Do.	9	B476	74	369	9/24/51	5
B429	79	891	7/10/51	11	B477	64	268	Do.	4
B430	51	207	Do.	5	B478	90	486	9/26/51	5
B431	79	370	Do.	5	B479	55	228	Do.	4
B432	70	581	Do.	8	B480	71	266	9/27/51	4
B433	60	304	7/11/51	5	B481	64	288	9/28/51	4
B434	54	318	Do.	6	B482	133	1028	Do.	8
B435	67	543	7/12/51	8	B483	76	355	10/4/51	5
B436	63	321	Do.	5	B484	49	284	10/5/51	6
B437	103	739	7/13/51	7	B485	127	609	10/8/51	5
B438	90	652	Do.	7	B486	103	460	10/9/51	4
B439	93	786	Do.	8	B487	50	179	Do.	4
B440	69	476	Do.	7	B488	83	446	Do.	5
B441	47	143	7/17/51	3	B489	67	275	10/10/51	4
B442	74	360	7/25/51	5	B490	36	192	10/11/51	5
B443	60	514	Do.	9	B491	59	243	10/12/51	4
B444	94	604	7/30/51	6	B492	60	305	10/16/51	5
B445	80	529	8/3/51	7	B493	40	112	Do.	3
B446	80	460	8/6/51	6	B494	96	670	10/18/51	7
B447	103	597	Do.	6	B495	71	377	10/19/51	5
B448	86	518	8/8/51	6	B496	95	644	Do.	7
B449	57	285	Do.	5	B497	85	440	10/25/51	5
B450	40	114	Do.	3	B498	82	412	10/30/51	5
B451	52	177	8/9/51	3	B499	76	407	10/31/51	5
B452	34	147	8/14/51	4	B500	88	380	11/2/51	4
B453	54	281	8/16/51	4	B501	73	299	11/5/51	4
B454	78	299	8/23/51	4	B502	78	243	11/6/51	3
B455	87	442	8/24/51	5	B503	76	410	11/7/51	5
B456	52	288	8/27/51	6					

1/ Examined for maturing eggs, maturing eggs present.

2/ Examined for maturing eggs, maturing eggs absent.

Table B.--Data on ovaries collected in the western equatorial Pacific

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position	
					Latitude	Longitude
1000	43	1645	38	4/15/51	6°52'N	148°38'E
1001	48	1401	29	4/18/51	4°35'N	150°01'E
1002	39	1926	49	4/20/51	2°10'N	152°10'E
1003	57	1575	28	5/17/51	2°00'N	161°00'E
1004	51	2001	39	5/13/51	1°55'N	160°53'E
1005	52[2/]	1067	21	5/17/51	2°00'N	161°00'E
1006	39	825	21	5/28/51	1°15'N	160°30'E
1007	38	1165	31	4/24/51	1°48'N	152°50'E
1008	39	305	8	4/19/51	--	--
1009	39	991	25	5/21/51	4°52°N	158°15'E
1010	34	848	25	4/19/51	--	--
1011[1/]	19	307	16	4/17/51	4°25'N	148°00'E
1012	44	693	16	5/14/51	1°30'N	161°50'E
1013	58	1445	25	5/27/51	3°40'N	158°02'E
1014	45	1208	27	5/23/51	4°45'N	163°00'E
1015	42	267	6	5/9/51	4°05'N	145°30'E
1016	43	923	21	5/23/51	4°45'N	163°00'E
1017	49	1365	28	5/23/51	6°45'N	160°00'E
1018	60	1610	27	4/26/51	3°20'N	152°50'E
1019	69	2605	38	5/23/51	4°45'N	163°00'E
1020	30	1173	39	4/27/51	2°05'N	153°30'E
1021	39	1094	28	5/21/51	4°52'N	158°16'E
1022	51	1293	25	5/13/51	1°55'N	160°53'E
1023	58	2024	35	4/16/51	5°20'N	147°50'E
1024	47	1181	25	4/14/51	1°40'N	160°45'E
1025	30	651	22	--	--	--
1026	48	1271	26	5/28/51	1°15'N	160°34'E
1027	51	1081	21	5/25/51	4°55'N	162°55'E
1028	45	1333	30	5/26/51	2°40'N	155°25'E
1029	68	1759	26	4/18/51	--	--
1030	64	1427	22	5/26/51	2°40'N	155°25'E
1031	64	2286	36	4/29/51	1°26'N	153°10'E
1032	88	2153	24	5/30/51	5°30'N	159°30'E
1033	68	1492	22	6/1/51	3°38'N	157°24'E
1034	38	801	21	5/23/51	4°45'N	163°00'E
1035	45	651	14	6/1/51	3°38'N	157°24'E
1036	30	268	9	6/5/51	1°28'N	154°22'E
1037	43	649	15	5/14/51	1°40'N	160°45'E
1038	--	458	--	3/30/51	--	--
1039	43	365	8	6/5/51	1°28'N	154°22'E
1040	45	331	7	4/2/51	--	--
1041	44	707	16	5/23/51	4°45'N	163°00'E
1042	32	1001	31	5/26/51	2°40'N	155°25'E
1043	26	184	7	6/7/51	2°20'N	154°25'E
1044	35	372	11	6/6/51	1°48'N	154°02'E
1045	39	767	20	5/28/51	1°15'N	160°30'E
1046[1/]	14	29	2	5/27/51	3°40'N	158°02'E
1047	46	431	9	4/6/51	3°30'N	145°20'E
1048	61	762	12	5/31/51	4°18'N	160°40'E
1049	53	443	8	6/4/51	1°18'N	154°55'E
1050	42	505	12	4/28/51	--	--
1051	59	961	16	6/10/51	3°20'N	155°10'E

Table B.--Data on ovaries collected in the western equatorial Pacific--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position	
					Latitude	Longitude
1052	45	692	15	4/27/51	2°05'N	153°30'E
1053	24	262	11	5/2/51	1°30'N	156°00'E
1054	48	699	15	6/5/51	--	--
1055	69	622	9	5/13/51	1°55'N	160°53'E
1056	56	667	12	5/23/51	4°45'N	163°00'E
1057	40	480	12	5/30/51	5°15'N	163°55'E
1058	45	317	7	6/7/51	4°00'N	156°10'E
1059	52	2522	48	4/19/51	--	--
1060	79	3038	38	6/1/51	3°38'N	157°24'E
1061	68	2793	41	4/25/51	2°20'N	153°05'E
1062	56 2/	1784 3/	32	6/24/51	5°53'N	158°50'E
1063	39 2/	1460 3/	37	7/19/51	4°-5°N	167°-168°E
1064	22 2/	492 3/	22	6/25/51	2°-3°N	156°-157°E
1065	54 2/	562 3/	10	10/19/51	7°-10°N	178°-179°E
1066	98 2/	2634 3/	27	9/16/51	3°30'N	164°E
1067	32 2/	218 3/	7	9/29/51	3°-8°N	166°-171°E
1068	37 2/	874 3/	24	7/17/51	2°-3°N	166°-167°E
1069	37 2/	654 3/	18	10/19/51	7°-10°N	178°-179°E
1070	95 2/	2102 3/	22	7/27/51	4°-5°N	168°-169°E
1071	23 2/	100 3/	4	7/17/51	2°-3°N	166°-167°E
1072	56 2/	660 3/	12	8/30/51	4°30'N	155°00'E
1073	28 2/	442 3/	16	9/28/51	2°-4°N	163°-167°E
1074	--	408 3/	--	9/21/51	2°-7°N	160°-166°E
1075	28 2/	140 3/	5	7/19/51	3°-8°N	166°-171°E
1076	83 2/	2802 3/	34	8/12/51	6°15'N	173°E
1077	21 2/	112 3/	5	9/20/51	1°-4°N	165°-170°E
1078	39 2/	1060 3/	27	7/16/51	2°02'N	166°51'E
1079	53 2/	1006 3/	19	8/14/51	7°-8°N	173°-175°E
1080	91 2/	2256 3/	25	7/29/51	5°-6°N	168°-169°E
1081	112 2/	1614 3/	14	10/8/51	6°25'N	178°00'E
1082 1/	13 2/	32 3/	2	7/15/51	3°55'N	164°45'E
1083	85 2/	908 3/	11	10/17/51	7°-8°N	177°-179°E
1084 1/	16 2/	60 3/	4	9/23/51	2°-5°N	161°-164°E
1085 1/	19 2/	30 3/	2	10/19/51	6°-8°N	174°-179°E
1086	60 2/	1044 3/	17	10/19/51	7°-10°N	178°-179°E
1087	30 2/	466 3/	16	?/21/5/	2°-7°N	160°-166°E
1088	21 2/	268 3/	13	7/19/51	4°-5°N	167°-168°E
1089	43 2/	308 3/	7	9/29/51	3°-8°N	167°-171°E
1092	75 2/	1526 3/	20	?/4/51	4°-5°N	159°-160°E
1093	59 2/	1314 3/	22	10/19/51	7°-10°N	178°-179°E
1094	97 2/	3204 3/	33	10/15/51	6°-8°N	171°-172°E
1095	54 2/	2474 3/	46	9/13/51	2°59'N	161°47'E
1096	28 2/	536 3/	19	9/22/51	1°-6°N	163°-167°E
1097	38 2/	462 3/	12	9/24/51	2°34'N	166°15'E
1099	38 2/	476 3/	13	10/19/51	7°-10°N	178°-179°E
1101	20 2/	97	5	9/22/51	1°-6°N	163°-167°E
1102	58 2/	1050 3/	18	10/19/51	7°-10°N	178°-179°E
1104	22 2/	120 3/	5	10/16/51	5°-7°N	176°-179°E
1105	25 2/	378 3/	15	10/19/51	5°-7°N	175°-177°E
1106	46 2/	324	7	9/24/51	?-5°N	163°-166°E

1/ Examined for maturing eggs, maturing eggs present.

2/ From length-weight relation, log weight = -7.1167 + 2.9304 log fork length. Relation calculated for bigeye of Hawaiian waters by POFI.

3/ Assumed that right ovary weight = left ovary weight.

Table C.--Data on ovaries collected in the central equatorial Pacific

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position: Latitude	Position: Longitude
1	85	1598	19	9/18/51	2°02'N	153°01'W
2	76	1230	16	9/4/51	1°59'N	150°02'W
3	102	2130	21	9/16/51	1°54'N	156°10'W
4	86	2137	25	9/13/51	2°02'N	156°10'W
5	94	1073	11	9/4/51	1°59'N	150°02'W
6	68	1377	20	9/4/51	1°59'N	150°02'W
7	104	2979	28	9/13/51	2°02'N	156°10'W
8	91	2217	24	9/12/51	1°54'N	155°14'W
9	73	2177	30	8/24/51	14°44'N	150°08'W
11	86	2132	25	9/13/51	2°02'N	156°10'W
12	107	2048	19	9/16/51	1°54'N	156°10'W
13	70	1701	24	9/6/51	2°04'N	153°02'W
14	102	1785	17	9/2/51	3°58'N	150°00'W
15	89	2086	23	8/27/51	9°43'N	150°00'W
17	99	2261	23	9/18/51	2°02'N	153°01'W
18	70	2153	31	8/24/51	14°44'N	150°08'W
19	108	2404	22	8/25/51	11°35'N	149°57'W
20	54	1237	23	8/24/51	14°44'N	150°08'W
21	67	1348	20	9/5/51	1°54'N	155°14'W
22	68	2129	31	8/24/51	14°44'N	150°08'W
23[1]	21	135	6	9/24/51	3°32'N	150°02'W
24	57	1442	25	8/24/51	14°44'N	150°08'W
26	52	683	13	8/25/51	1°35'N	149°57'W
27	85	774	9	8/31/51	5°58'N	149°55'W
28	64	1360	21	8/24/51	14°44'N	150°08'W
29[1]	75	461	6	8/29/51	8°01'N	149°53'W
30	57	970	17	9/18/51	2°02'N	156°10'W
31	72[3]	1597	22	8/23/52	5°16'N	140°28'W
32	81[3]	1984	24	8/30/52	3°37'N	140°27'W
33	72[3]	1726	24	8/23/52	5°16'N	140°28'W
34	93[3]	2096	23	9/5/52	2°25'N	140°32'W
35	85[3]	1239	15	9/6/52	2°06'N	140°56'W
36	85[3]	567	7	9/4/52	3°20'N	140°10'W
37[1]	85[3]	370	4	9/12/52	2°26'N	148°52'W
38	56[3]	584	10	9/6/52	2°06'N	140°56'W
41[1]	45[3]	236	5	5/29/52	7°09'N	119°00'W
42[1]	105[3]	524	5	5/28/52	8°55'N	119°07'W
43	77[3]	993	13	5/31/52	4°18'N	119°35'W
44	47[3]	331	7	5/29/52	7°09'N	119°00'W
45[1]	47[3]	178	4	5/29/52	7°09'N	119°00'W
46	29[3]	139	5	5/30/52	5°27'N	119°38'W
47[1]	48[3]	269	6	6/13/52	8°00'N	130°24'W
48	85[3]	1837	22	6/13/52	8°00'N	130°24'W
51	90	2818	31	8/31/52	6°27'S	140°03'W
53[1]	89	376	4	9/3/52	1°14'S	140°02'W
54[1]	51	214	4	9/3/52	1°14'S	140°02'W
55	77[3]	571	7	9/6/52	2°01'N	141°21'W
56	104	3732[4]	36	9/1/52	4°51'S	140°09'W
57	96	4989	52	9/2/52	3°14'S	140°06'W
60	39[3]	1268	32	2/2/52	2°46'N	155°11'W
61	51	359	7	1/29/52	8°02'N	154°58'W
62	--	1079	--	1/31/52	5°20'N	155°00'W

Table C.--Data on ovaries collected in the central equatorial Pacific--Continued

Ovary No.	Fish weight kg.	Ovary weight gm.	Relative ovary weight x 10^3	Date collected	Position	
					Latitude	Longitude
63	65[3]	2351	36	2/2/52	2°46'N	155°11'W
64	45[3]	339	7	1/31/52	5°20'N	155°00'W
65	32[3]	232	7	1/31/52	5°20'N	155°00'W
70[2]	61[3]	224	4	1/26/53	15°46'N	154°13'W
71	64[3]	603	9	3/15/53	1°00'N	140°00'W
72	59	1402	24	3/6/53	10°09'S	144°31'W
73	79	552	7	3/13/53	1°00'S	140°05'W
74	84	874	10	3/13/53	1°00'S	140°05'W
75	74[3]	835	11	2/12/53	1°13'S	150°03'W
76	78[3]	648	8	2/12/53	1°13'S	150°03'W
77[1]	41	428	10	2/16/53	1°55'S	150°07'W
78	100[3]	1661	17	2/15/53	1°26'S	150°45'W
79	111[3]	2734	25	3/18/53	4°12'N	140°20'W
80	83	369	4	10/31/52	5°35'S	120°28'W
81	93	1083	12	11/2/52	9°39'S	120°47'W
82	64	330	5	11/6/52	3°14'S	130°19'W
83	66	274	4	11/9/52	1°11'N	130°23'W
90	73	1558	21	11/19/52	5°00'S	170°08'W
91[1]	99	557	6	10/19/52	17°22'N	156°21'W
92[1]	101	607	6	10/19/52	17°22'N	156°21'W
93	121	3085	25	10/27/52	5°34'N	152°20'W
94	100[3]	2067	21	10/25/52	5°06'N	152°11'W
95	83	2669	32	10/29/52	3°13'N	152°05'W
100[1]	47	225	5	5/4/53	8°31'N	150°17'W
101[1]	50	258	5	5/6/53	5°30'N	150°00'W
102	46[3]	307	7	6/8/53	6°13'N	170°07'W
103	40[3]	265	7	6/8/53	6°13'N	170°07'W
104	60[3]	670	11	6/8/53	6°13'N	170°07'W
110	47	1540	33	7/29/53	9°57'N	155°06'W
111	82	1657	20	7/29/53	9°57'N	155°06'W
112	59	1232	21	7/30/53	8°39'N	154°57'W
113[2]	28	77	3	7/31/53	7°15'N	155°04'W
114[1]	20	25	1	7/31/53	7°15'N	155°04'W
115	29	213	7	7/31/53	7°15'N	155°04'W
116	32	305	10	7/31/53	7°15'N	155°04'W
117	28	207	7	7/31/53	7°15'N	155°04'W
118	42[3]	870	21	8/1/53	6°06'N	154°49'W
119	53[3]	835	16	8/1/53	6°06'N	154°49'W
120	97[3]	2000	21	8/1/53	6°06'N	154°49'W
121[1]	17[3]	94	6	8/5/53	2°02'N	156°13'W
122	102	2295	22	8/26/53	7°50'N	159°24'W
123	66[3]	1075	16	8/27/53	4°43'N	160°00'W
124	74[3]	1645	22	8/26/53	7°50'N	159°44'W

1/ Examined for maturing eggs, maturing eggs present.

2/ Examined for maturing eggs, maturing eggs absent.

3/ From length-weight relation, log weight = -7.1167 + 2.9304 log fork length. Relation calculated for bigeye of Hawaiian waters by POFI.

4/ Assumed that right ovary weight = left ovary weight.